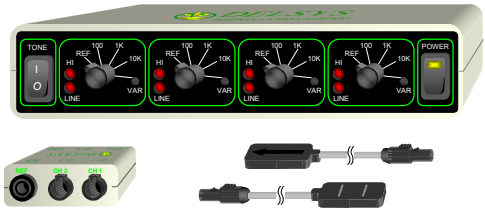
DELSYS®

The Bagnoli-4 EMG System



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Bagnoli-4 EMG System

User Manual

May 2003 Edition

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IMPORTANT INFORMATION

Intended Use

The Bagnoli EMG Systems are designed for research, investigational and scholarship purposes only. DelSys products are not intended for measurement purposes or for use in the treatment and diagnosis of humans.

Warnings and Precautions

Delsys products are not designed to be used in conjunction with any devices not approved by Delsys Inc. Please contact Delsys for further information.

Connecting a patient to high-frequency surgical equipment while using Delsys EMG systems may result in burns at the site of the EMG sensor contacts.

Immediately discontinue device use if skin irritation or discomfort occurs.

Immediately discontinue device use if a change in the device's performance is noted. Contact Delsys technical support for assistance.

Do not use Delsys products in the presence of any liquid or during conditions where the device or the user(s) may become exposed to liquids. The presence of liquids may compromise the safety features of the devices.

Delsys EMG amplifiers are extremely sensitive to electrical disturbances. Avoid static discharges and electromagnetic fields.

Delsys Inc. guarantees the safety, reliability, and performance of the equipment only if assembly, modifications and repairs are carried out by authorized technicians; the electrical installation of the relevant room complies with the appropriate requirements; and the equipment is used in accordance with the instructions for use.

Certifications

European Community

Bagnoli EMG Systems satisfy the Essential Requirements put forth by the "Medical Device Directive" 93/42/EEC concerning the distribution of devices in Europe.

Compliance

Bagnoli EMG System comply in full with the relevant clauses of the following standards:

EN60601-1:	Medical Electrical Equipment (IEC 601, UL2601)
EN60601-1-2	Electromagnetic Compatibility- Requirements and Tests
EN60601-2-40:	Specification for electromyographs and evoked response equipment
EN980:	Graphical symbols for use in the labeling of medical devices
ISO10993-1:	Biological evaluation of medical devices

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Limited Warranty

The Bagnoli-4 systems are warranted against failure of materials and workmanship for a period of 1 year from the date of delivery, provided that the product is given proper care and has not been subject to abuse during this period. This warranty is in lieu of all other warranties expressed or implied. Operation of this device outside specified power supply or input voltage ranges specified by DELSYS INC. or use with any other input devices other than DELSYS INC. electrodes constitute an invalidation of this limited warranty. This warranty is not transferable.

All devices to be returned require a return authorization number issued by DELSYS INC. All authorized returned merchandise must be shipped prepaid to DELSYS INC. If authorization for the return of a device is given, please insure the product in transit for any loss or damages that may occur.

Technical Support

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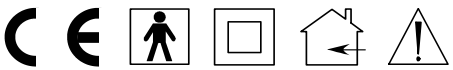

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The Bagnoli-4 EMG System

General Description

The Bagnoli-4 EMG System is designed to make the acquisition of EMG signals hassle-free and reliable. The active electrodes are specifically designed to optimally detect EMG signals at the skin surface, while rejecting common noise signals such as motion and cable artifacts, yielding an excellent signal-to-noise ratio. Gains of 100, 1000 or 10000 can be selected for the ideal acquisition of different amplitude signals. There is as also a variable gain control available so that any amplification factor between 100 and 10000 can be chosen. Each of the four channels is equipped with two signal quality checks: one for the presence of line interference in the signal and one for amplifier saturation caused by an excessive gain setting. These errors are signaled by the illumination of yellow LEDs located on the front panel of the unit, and by an optional audio buzzer. The unit is powered by an isolated medical grade power supply, with leakage currents less than 10uA and safety isolated to 3750 V_{RMS}. The integration of all these features in a lightweight desktop unit lends the Bagnoli-4 practical in both lab and field environments.

The Bagnoli-4 EMG System is comprised of the following items:

- four active Differential Surface Electrodes
- one Main Amplifier Unit
- one belt-mounted Interface Unit
- one Reference Electrode Cable
- one Interface Unit I/O Cable
- one Power Supply

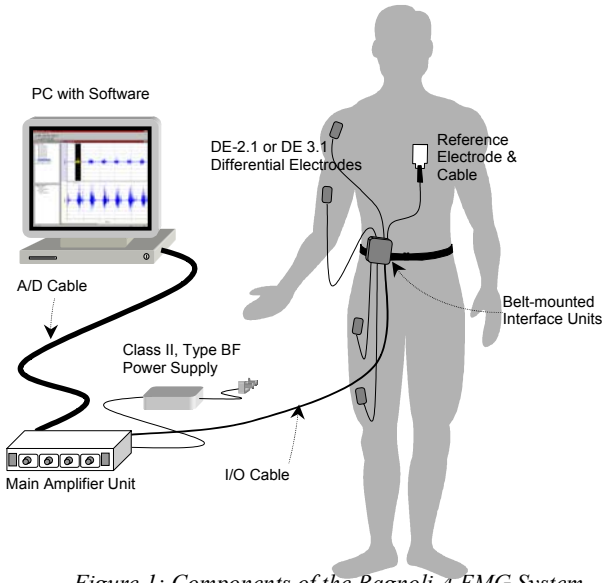


Figure 1: Components of the Bagnoli-4 EMG System

The DE-2.1 Differential Surface Electrode

The differential electrode subtracts EMG potentials detected at two distinct locations on the surface of the skin, directly above an active muscle. The EMG potentials are always measured with respect to the electric potential of a neutral inactive site located away from the EMG muscle source. The electric potential of this neutral site is commonly termed "the reference" potential, and is accessed by the Reference Electrode.

The electrode housing is constructed with a waterproof polycarbonate plastic case, which is internally shielded to reject ambient electrical noise. The electrode contacts are made from 99.9% pure silver bars measuring 10 mm in length, 1 mm in diameter and spaced 10 mm apart for optimal frequency capture. It is these contacts that detect the EMG potentials described above. The detected signals are subtracted and then amplified before being sent along a shielded cable to the rest of the EMG system. The 5-ft electrode cable terminates in a circular connector that hosts four contacts: two for power, one for the reference potential, and one for the electrode output. This connector mates with its socket located on the belt-mounted Interface Unit.

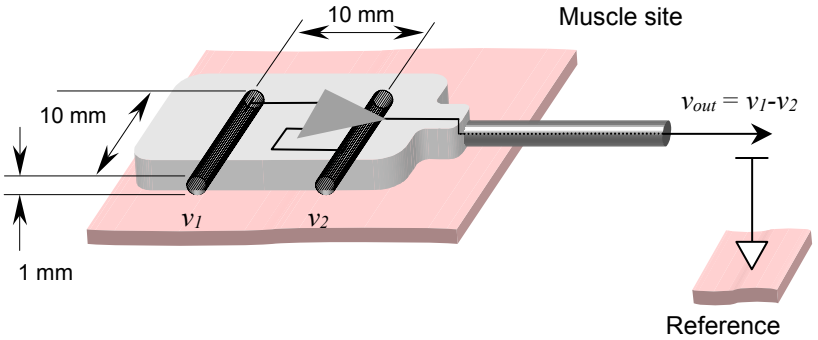


Figure 2: The DE-2.1 Single Differential Electrode. The EMG signal is the result of the potential difference between v_1 *and* v_2 *on the skin surface.*

The DE-3.1 Double Differential Electrode (Optional)

The DE-3.1 Double Differential Electrode is not included in the standard Bagnoli-4 EMG system and must be purchased separately. It is specifically designed to reduce the presence of EMG crosstalk emanating from muscles underneath and adjacent to the muscle of interest. The external dimensions of the electrode and the electrode bars are identical to the standard DE-2.1 electrodes. This unit however uses 3 bars instead of 2. It works on the principle that a signal originating from a source further away (some other muscle) will arrive at adjacent detection surfaces with less relative latency than a signal which originates from the muscle beneath the electrode. By performing two subtractions, the signals with short relative latency (those originating from distant sources) will cancel out.

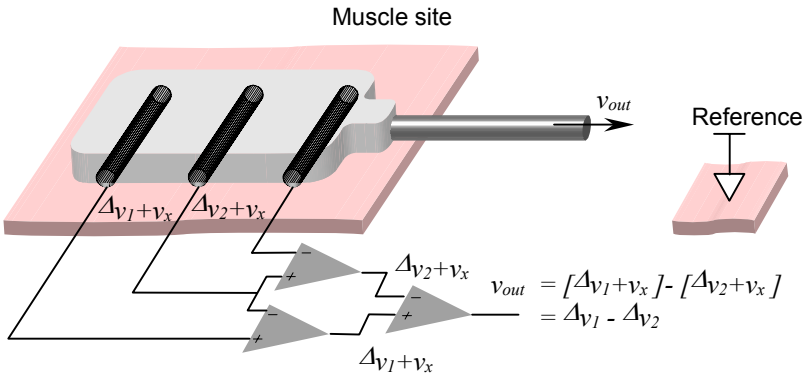


Figure 3: The optional DE-3.1 Double Differential Electrode. EMG crosstalk signals originating from far sources (v_x) remain relatively unchanged across the three contact bars when compared to the EMG signals originating immediately under the bars. The v_x components are cancelled in the double differential recording. Note that the EMG potential present in the middle contact appears in both Δv_1 and Δv_2. This causes the output amplitude of the signal to be approximately 1.5 times larger than the single differential electrode

The Main Amplifier Unit

This desktop unit supplies power to the EMG Electrodes, receives and conditions the signals detected by the EMG Electrodes, and provides 4 analog channel outputs which can be accessed by BNC connectors or by a D-Sub type connector. Each channel has a selectable gain which can be set to a factor of 100, 1000 or 10000. There is also a "REF" setting, which forces the output of the channel to the reference potential. The Main Unit filters the EMG signals to a bandwidth between 20 Hz and 450 Hz, and checks for excessive amounts of line interference, as well as channel clipping due to over-amplified signals. The presence of these errors is signaled via red LEDs, and through a user-enabled audio buzzer alarm.

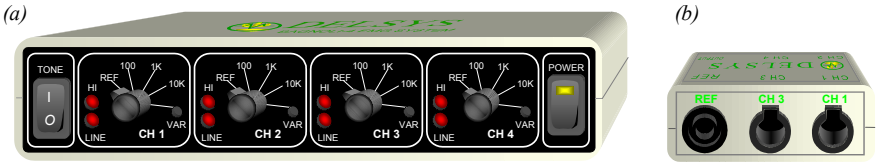


Figure 4: (a) The Main Amplifier Unit. (b) The Belt-mounted Interface Unit.

The Belt-mounted Interface Unit

This is a lightweight connection box that hosts four EMG Electrodes and the Reference Electrode cable. The EMG signals detected by the electrodes are communicated to the Main Amplifier Unit via the Interface Unit I/O Cable, an umbilical that also carries power to the electrodes. The unit has a clip on one side, which allows easy fastening to waist belts or other articles of clothing.

The Reference Electrode Cable

This is a single-conductor wire with a "banana" connector on one end and an "alligator clip" on the other end. The banana plug is hosted by a receptacle located in the belt-mounted Interface Unit. The alligator clip can be connected to any conductive adhesive patch placed on an inactive site on the body. It is important that the Reference Electrode have a high quality electrical connection with the skin.

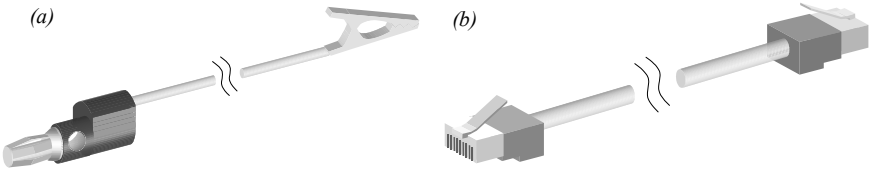


Figure 5: (a) The Reference Electrode Cable. (b) The Interface Unit I/O Cable.

The Power Supply

The Bagnoli-4 is equipped with one of two Medical Grade power supplies. The domestic power supply conforms to the medical UL544 standard, and is approved by the FDA. This wall mounted supply provides a regulated 12 Volt output for the Bagnoli-4 System, with leakage currents below 10 μA. Alternatively a wide-voltage input Medical Grade power supply is included for use in foreign countries. This accepts inputs of from 60 to 240 V_{rms} at either 50 Hz or

Using the Bagnoli-4 EMG System

All input/output connections of the Main Unit Amplifier are located on the rear panel of the assembly (shown in *Figure 6*), while the front panel (shown in *Figure 4(a)*) hosts the EMG channel controls, the error detection information and the main power switch.

Connecting the Power Supply

The power supply is connected to the circular DIN socket on the left side of the rear panel labeled "12 VDC", as shown in *Figure 6*. Note that the connector is polarized, so that it can only be inserted with the correct orientation. The 3-prong line-voltage plug of the power supply should be inserted in a properly functioning and grounded power supply outlet.

North American Power Supply

Units sold in the United States and Canada are equipped with a 120 VAC, 60 Hz regulated Medical Grade power supply manufactured by Elpac. This supply conforms to the UL544 medical standard, the IEC 60601 medical standard and has CSA and UL approval.

CAUTION: Bagnoli-4 Systems fitted with the ELPAC MED 144 power supply must only be plugged into 120 VAC U.S. and Canadian receptacles. Failure to use the power supply with properly rated receptacles may damage the system and create hazardous situations.

International Power Supply

Units sold outside the United States or Canada are equipped with a variable-input Medical Grade power supply. The input can range from 100 to 250 VAC and 50 to 60 Hz. This supply conforms to UL2601, CSA601 and TUV/IEC 60601-1 safety standards. The supply is fitted with a universal IEC 320 input plug so as to accept power cables from several countries.

CAUTION: Always ensure that the voltage input switch on the power supply is correctly set to accept the mains voltage of your location. An incorrect setting may damage the power supply.

CAUTION: Bagnoli-4 Systems are equipped with a specially made power supply. Using a power supply other than the one provided may damage the system and create hazardous situations.

CAUTION: Always use an IEC320 power cable and properly functioning mains receptacle for powering the Bagnoli-4 EMG System. A disconnected ground plug can result in shock hazards

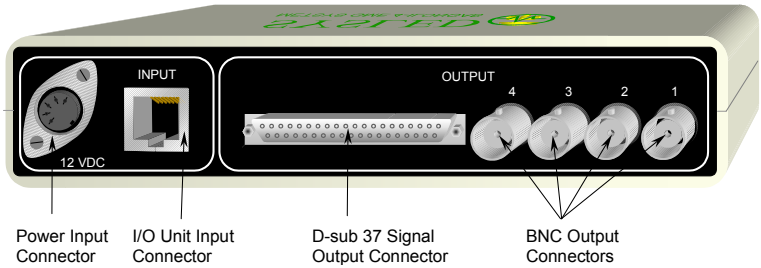


Figure 6: The back panel of the Main Amplifier Unit. All power, input and output connections are made on this panel.

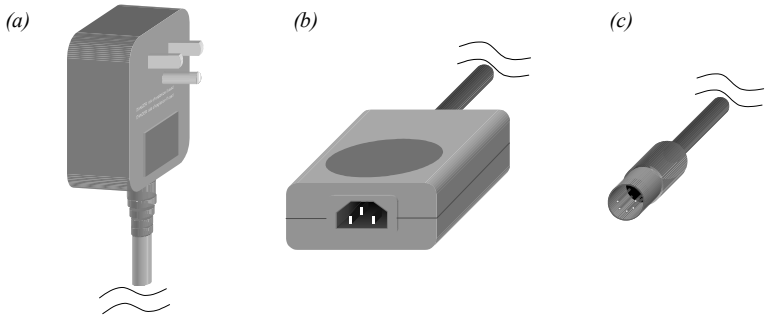


Figure 7: (a) The Elpac MED 144 North American power supply. (b) The Ault SW172 wide input power supply. (c) The Bagnoli-4 power input connector

Connecting the Input Signals

Connecting the Interface Unit and Associated I/O Cable

The Interface Unit I/O cable bridges the portable Interface Unit with the Main Amplifier Unit. Each end of the 25-foot cable terminates in a shielded RJ-45 connector. One end of the cable is inserted in the I/O input socket located on the rear panel of the Main Amplifier Unit while the opposite end of the cable is inserted in a similar socket labeled "OUTPUT" on the Interface Unit as shown in *Figure 8*. The Interface Unit is equipped with a belt-clip to facilitate its attachment to the user.

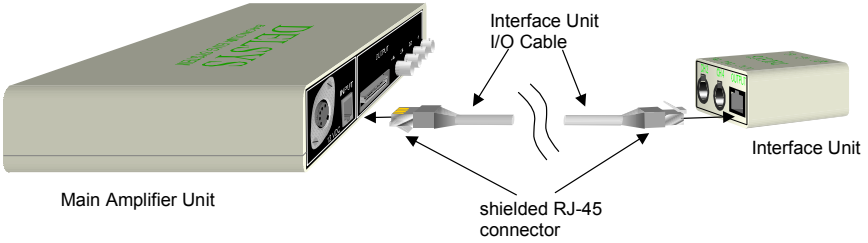


Figure 8: Connecting the Main Amplifier Unit and Interface Unit via the I/O cable.

Connecting the EMG Surface Electrodes to the Interface Unit

The Bagnoli-4 EMG Unit is supplied with four DE-2.1 Surface EMG electrodes. These plug into the receptacles labeled Ch.1 to Ch.4 on the Interface Unit. Channel 1 and Channel 3 are located on the opposite panel of the Interface Unit as Channel 2 and Channel 4. The connectors have a key so that they can only be inserted with a specific orientation. The order of the electrodes can be interchanged with no consequences to the performance of the EMG System. The electrode cables are five feet in length so that they can be placed on any part of a typical user's body when the Interface Unit is mounted at waist level.

Connecting the Reference Electrode

The Bagnoli-4 EMG Unit is supplied with a reference electrode cable terminating in a "banana" style plug on one end, and an "alligator" clip on the other end. The banana plug is fitted in the receptacle labeled "REF" on the Interface Unit. The alligator clip is used to connect to the conductive adhesive tabs supplied with the unit. The clip is used to pinch the dry edge of the adhesive electrodes, as depicted in *Figure 9*.

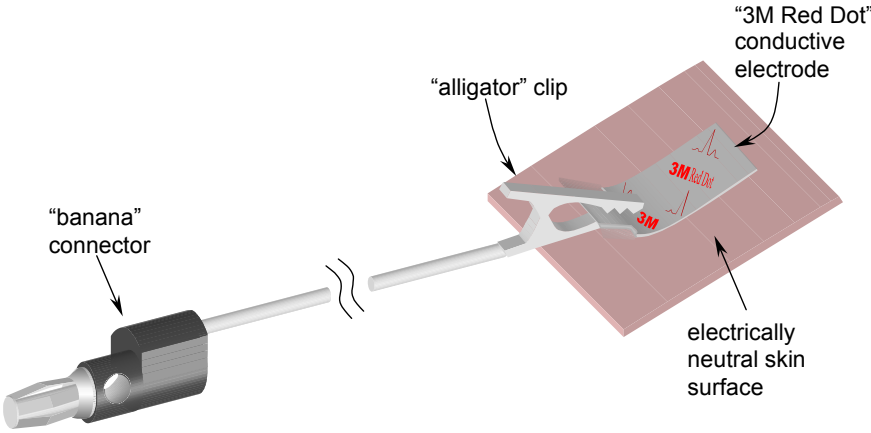
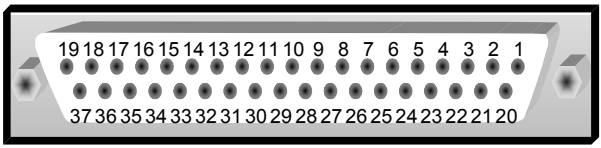


Figure 9: The Reference Electrode. The "banana-style" connector is mated with the Interface Unit, while the "alligator" clip is used to connect to conductive adhesive electrodes.

Connecting the Output Signals

The Bagnoli-4 EMG System outputs 4 single-ended voltage signals in the ± 5 Volt range. The rear panel of the Main Unit hosts two types of output connections: 4 BNC sockets and one D-Sub 37 female connector, as shown above in *Figure 6*. The BNC connections provide easy access to oscilloscope inputs, while the 37-pin connector can be used to directly access an A/D data acquisition system. The pinout of the D-Sub 37 connector is shown in *Figure 10*.



Pin	Signal
37	Channel 1
36	Channel 2
35	Channel 3
34	Channel 4

Figure 10: Signal pinout of the D-Sub 37 output connector .

Note: The input impedance of any device used to connect to the outputs of the Bagnoli-4 EMG System should be at least 1 MΩ. The output impedance of each Bagnoli-4 EMG channel is 15 KΩ.

Using the Electrodes

Orienting the Electrodes on the Skin

The DE-2.1 Surface EMG Electrode is fitted with two silver bar contacts for detecting the EMG signal at the skin surface. It is crucial that the orientation of these bars be perpendicular to the muscle fibers for maximum signal detection. The top of the electrode is stamped with an arrow to aid in the determination of this orientation. The arrow should be placed parallel to the muscle fibers underneath the electrode as demonstrated in *Figure 11*. It is important that the electrode and the skin are clean and free of oil and other resides before placement of the electrodes. It is advised to remove excessive hair from the EMG site. The electrodes are easily attached to the skin with the DelSys Electrode Interface. Alternatively, surgical tape may be used.

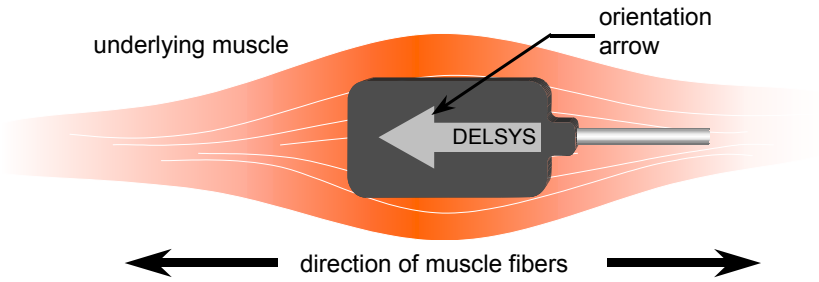


Figure 11: Electrode orientation with respect to the muscle fibers. It is important that the orientation arrow on the electrode be parallel to the underlying muscle fibers.

Using the DelSys Electrode Interface

The DelSys Interfaces are made from medical grade adhesive specifically designed for dermatological applications. Usage of the interface promotes a high quality electrical connection between the electrode bars the skin, minimizing motion artifacts and the ill-effect of line interference. To ensure a strong bond with the skin, it is advised to shave excessive hairs and wipe the skin area with isopropyl alcohol, to remove oils and surface residues. Allow the skin to dry completely before applying the interfaces. *Figure 12* illustrates the correct application of the Interface.

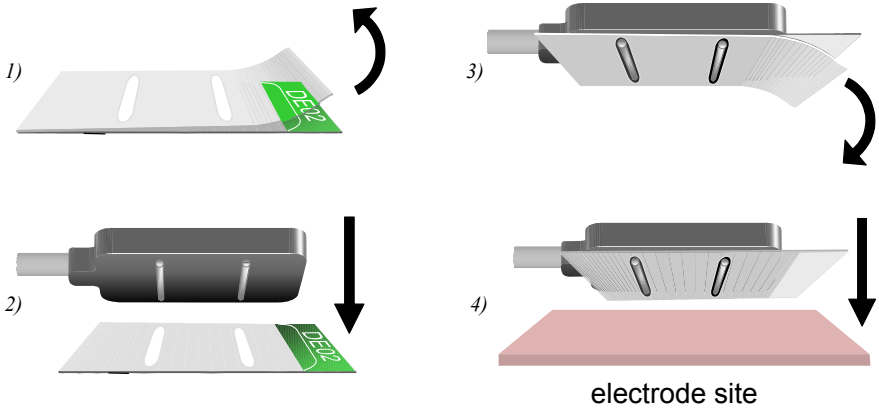


Figure 12: Application of the DelSys Electrode Interface. 1) Peel the top clear liner to expose the first layer of adhesive. 2) Mount the interface on the electrode, taking care to align the electrode contacts through the interface slots. 3) Peel the white liner located on the bottom side of the interface, to expose the second layer of adhesive. 4) Attach the electrode to the desired muscle site on the skin surface.

Attaching the Reference Electrode

Having a high quality electrical connection between the Reference Electrode and the skin is just as important for obtaining reliable EMG signals as having a high quality skin-EMG Electrode connection. The Reference site should be an electrically inactive area on the skin surface. The DelSys EMG Systems are supplied with 3M EKG electrodes, which are lined with a conductive medical grade adhesive (previously shown in *Figure 9*). As with the EMG electrode, conduction characteristics are optimized with proper skin preparation, which include shaving excess hair and wiping the skin with isopropyl alcohol. Conductive electrodes other than the examples supplied can be used as substitutes (*Figure 13*).

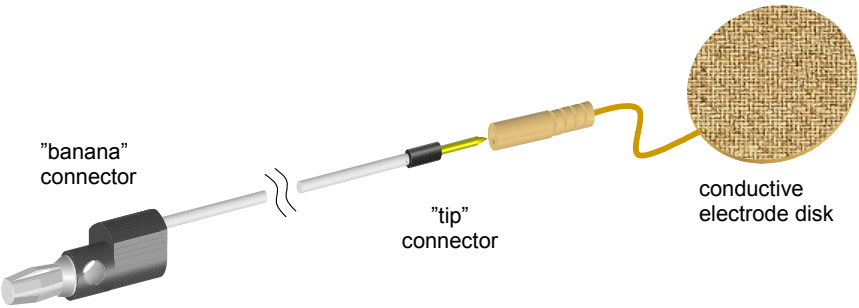


Figure 13: Alternative Reference electrode cable used with conductive disk electrode.

The Bagnoli-4 EMG System Controls

Turning the System "ON"

The main power switch is located on the far right side of the Main Amplifier Unit's front panel, with the word "POWER" appearing directly above it. The switch is labeled with an "I" to indicate the "on" position and an "O" to indicate the off position, or with an LED that illuminates in the "on" position. The rocker switch is in the "on" position when the top half is depressed, and in the "off" position when the bottom half is depressed. It is normal for all the LEDs on the front panel to illuminate for a brief moment when the unit is initially turned on. If any of the LEDs do not turn off after 2 seconds have passed, refer to the Error Detection Features section of this manual. If the unit does not turn on after enabling the main power switch, refer to the Troubleshooting section of this manual.

Selecting Appropriate Amplifier Gains

There are four knobs located on the front panel of the Main Amplifier Unit, each controlling the gain of one channel. Each knob can be set to one of the following options:

REF This position forces the input to the channel to be the reference potential. No EMG signals can be detected with this setting. All channels not in use should be set to the REF position to minimize the unwanted detection of noise and its detrimental effects due to channel crosstalk.

100 This setting gives the system an overall gain of 100. Gains of 100 should be used when recording abnormally large EMG signal amplitudes. Surface potentials ranging from ±10 mV to ±50 mV will result in output signal voltages of ±1 to ±5 Volts. Using this gain on EMG signals lower than ±10 mV will result in recorded signals of poor resolution.

1K This choice sets the overall system gain to a factor of 1000. This is the nominal gain for typical surface EMG signals ranging from ±1 mV to ±5 mV, resulting in output voltage signals of ±1 to ±5 Volts.

10K Knobs in this position set the channel gain to a factor of 10000. This extremely sensitive gain should only be selected when attempting to record particularly faint EMG signals, in the range of ±100μV to ±500μV. Once again the output yielded is ±1 to ± 5 Volts

VAR This setting allows the user to define a gain between the range of 100 and 10K. The gain can be set by turning the screw of the inset potentiometer with a small screwdriver or "trimmer tool".

Error Detection Features

Each channel of the Bagnoli-4 EMG System is equipped with two LEDs on the front panel of the Main Amplifier Unit signaling the presence of excessive line interference and the presence of signal clipping due to amplifier saturation.

Line Interference Detector

When lit, the LED labeled "LINE" on the front panel of the Main Amplifier Unit indicates an excessive presence of line interference in the channel. This line interference is typically caused by poor electrode-skin connections or by unconnected electrodes. To avoid the presence of line interference, ensure that both EMG electrode contacts are in contact with the skin surface, and that the Reference Electrode is appropriately attached. Failure to establish high quality electrode-skin connections with either the EMG sensor or the reference electrode will result in line interference. If the electrode-skin connections appear to be fine, and the "LINE" warning LED is still lit, refer to "Excessive Presence of Line Interference" in the "Troubleshooting" Section. Note that in North America line interference appears as a cyclic signal with a fundamental frequency of 60 Hz. In Europe and some other countries, this cyclic signal has a fundamental frequency of 50 Hz. The Bagnoli-4 EMG System is set to the line frequency of the destination country at the time of manufacturing. Note also that the EMG system will only detect deterministic signals, so that any 60 Hz components in the EMG signal will not trigger the alarm.

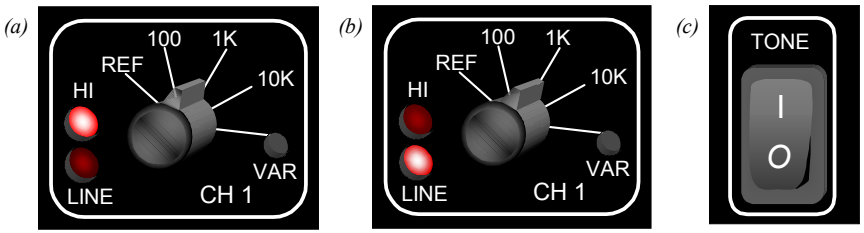


Figure 14: The LED error detection indicators. (a) the power-line interference warning, (b) the saturation indicator, (c) the audible tone switch.

Saturation Level Detector

Due the amplitude variability of the EMG signal, it is possible to saturate the amplifiers if the channel gain is set too high. The Bagnoli-4 EMG System is designed to operate with an output in the range of ±5 V. Furthermore, typical A-D acquisition systems accept inputs in the range of ±5 V, and problems with over-voltages may affect their operation. For these reasons it is strongly recommended that the channel gains be set so that the output is within the ±5-Volt range. A yellow LED indicator labeled "HI" on the front panel of the Main Amplifier Unit is included to aid the user in selecting the appropriate gain. This LED illuminates whenever the amplitude of the output signal exceeds ±4.8 Volts. Should this situation arise during use of the Bagnoli-4 EMG System, it is

recommended that the gain be dropped by a factor of 10. Note that transient signals, such as motion artifacts or static discharges, may trigger the "HI" alarm.

Audible Buzzer Alarm

An audible buzzer alarm is included to aid in the monitoring of line interference and saturation errors. The switch on the far left of the Main Amplifier Unit's front panel labeled "TONE" is used to enable and disable the audio alarm. When enabled, the alarm will sound if at least one of the yellow LED indicators on the front panel illuminates. This feature allows the user to check for error conditions without needing to see the LED indicators on the front panel. The alarm is enabled with the digit "I" on the switch is depressed, and disabled when the digit "O" on the switch is depressed.

Maintenance and Care of the Bagnoli-4 EMG System

The Main Amplifier Unit and Interface I/O Unit

While the Main Amplifier Unit and the portable Interface I/O Unit cases are made of durable plastic, the following points should be kept in mind when using and handling the Bagnoli-4 EMG system:

- The Bagnoli-4 units can be easily cleaned with a damp cloth and mild detergent. Take care not to wear out the ink on the panels when cleaning.
- The units are not shockproof and should not be dropped or be subjected to excessive forces or accelerations.
- Ample strain relief for the interconnecting cables should be provided so that none of them are under excessive tension. Do not pull on any of the interconnecting cables.

Never use any electrode other than the DE-2.1 or the DE-3.1 DelSys Electrodes as inputs to the Bagnoli-4 EMG System. Connecting any other electrode as inputs to the Bagnoli-4 EMG system constitutes an invalidation of the DelSys Warranty and may result in personal injury and/or permanent damage to the system or the electrodes.

The Main Amplifier Unit and the I/O Interface Unit are not water-resistant. Under no circumstance should the units be exposed to water or any other type of liquids. CAUTION: The risk of electric shock exists if the Main Amplifier Unit is operated while in contact with liquids.

The DE Series Electrodes

The DE-2.1 electrodes are encased in a sealed polycarbonate case. The following points should be kept in mind when handling the electrodes.

- The electrodes can be cleaned and sterilized with a damp cloth and mild detergent or with isopropyl alcohol swabs. It is crucial that the electrode contacts remain clean at all times.
- The electrodes are completely sealed and are water-resistant. These can be used on damp skin surfaces and in the presence of sweat without compromise to safety, electrode integrity or operation. The electrodes should never be completely submerged in any liquid.
- The electrode contacts are made of pure silver and are quite soft. Care should be taken to preserve the integrity of these contacts. Do not scrape or dent these contacts.
- Do not pull on the electrode cable. Avoid kinks in the cable, as these will result in damage to the internal cable wires and intermittent connections.
- Handle the electrode with care: do not drop them on the ground or step on them.

The electrodes must only be used with DelSys EMG Systems. The DE-2.1 and the DE-3.1 electrodes are specifically designed for the Bagnoli series EMG Systems. Using these electrodes as inputs to any other EMG system constitutes an invalidation of the DelSys Warranty and may result in personal injury and/or permanent damage to the electrodes or the system.

The electrode contains sensitive electronic circuitry. Static discharges and intense magnetic fields should be avoided to prevent possible irreparable damage to the electrodes.

Troubleshooting

Excessive Presence of Line Interference

Power line interference from surrounding sources is always an issue to contend with when recording body potentials on the surface of the skin. This interference is due to the presence of a 60 Hz (or 50 Hz) displacement current flowing on the skin surface due to the capacitance between the body and ground and between the body and surrounding power sources (refer to *Figure 15*). People are exposed to this surface current on a continual basis, as it is present anytime a body is near an AC power source. This current cannot be sensed or felt, and poses no risk to the body it is flowing on.

The surface potentials resulting from this displacement current on the skin can be orders of magnitude larger than the EMG potentials being detected by the elec-

trodes. If the EMG system is working correctly, however, the detected amplitude of these interfering potentials are negligible when compared to the detected EMG potentials. Recall that the output of the EMG electrode is a subtraction of the potentials detected at the electrode contacts. The interfering potentials are large signals and change very little as they propagate across the space of the electrode contacts. The EMG potentials, on the contrary, change drastically as they propagate between the electrode bars. Ideally, the result is a differential EMG signal with a complete subtraction of the line interference (refer to *Figure 15 (b)*).

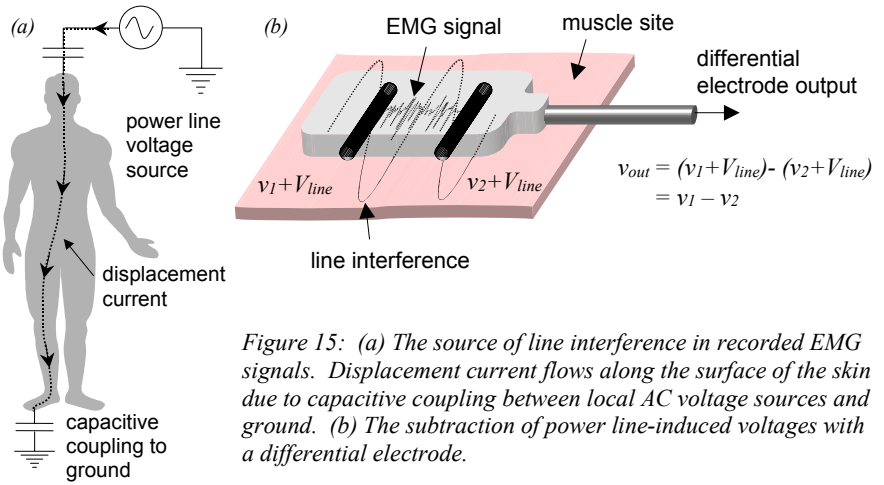


Figure 15: (a) The source of line interference in recorded EMG signals. Displacement current flows along the surface of the skin due to capacitive coupling between local AC voltage sources and ground. (b) The subtraction of power line-induced voltages with a differential electrode.

Line interference becomes overwhelmingly apparent if either of the following conditions arises: (a) the electrode does not subtract signals in an ideal fashion, (b) the quality of one or more electrode-skin contacts becomes compromised. The interference will appear as a high amplitude cyclic signal with a frequency of 60 Hz (for North American AC sources) or 50 Hz (for European, Australian and other foreign-country AC sources).

The first condition is intrinsic to the construction of the electrode preamplifier. The parameter used to gauge the electrode's ability to subtract signals ideally is called the common-mode rejection ratio (CMRR) and is measured in decibels. Most surface bio-potential applications require a minimum CMRR of 80 dB. DelSys EMG electrodes have a typical CMRR of 92 dB, with a minimum at 84 dB. An electrode capable of subtracting signals perfectly would have an infinite CMRR.

The second condition is within the user's control, and is attributable to most instances of excessive line interference. It is crucial that the reference electrode and all the silver bars of the EMG electrodes make a high quality electrical connection with the surface of the skin. Failure to establish a high quality connection will drastically increase the probability of observing line interference. The

following checklist should help in eliminating potential problem areas.

1. **Turn "off" surrounding power sources**. While it is generally not feasible to completely cut all the power in the ambient experimental area, all electronic equipment not in use should be turned off. The more AC power sources in the experimental area there are, the higher the probability of line interference. Pay careful attention to high current devices which radiate strong magnetic and electric fields such as motors, transformers, lights and equipment power supplies. If a portable computer is being used, it is advisable to disconnect the power supply (as these tend to be quite noisy) and run the machine from battery power for the data acquisition portion of the experiment.
2. **Check electrode-skin contact.** Ensure that all the electrodes are aggressively attached to the skin. The electrodes should not be easily dislodged when pulled by the connecting cables. Any portions of the electrode contacts not firmly pressed against the skin will result in line interference. The use of the DelSys Electrode Interfaces is recommended for this purpose. Refer to the section on "Poor Electrode-Skin Adhesion" if this is a problem.
3. **Clean the skin.** Ensure that the skin under all the electrodes is clean and free from hair. The area should be wiped with isopropyl alcohol swabs before the electrodes are applied. If necessary, hair can be removed with a safety razor or with commercially available hair removing lotions such as "Neet" or "Nair".
4. **Allow the electrode to settle.** When first applied to the skin, the electrode may display high levels of noise and interference. Allow the electrode to settle for a few minutes, giving time for the ionic currents between the electrode and the skin to become established. Wetting the electrode bars with water will expedite this process.
5. **Use surfactants.** On particularly dry skin, it may be necessary to wet the EMG electrode contacts with water or to line them with electrode gel so as to promote the necessary ionic flow. For this purpose, it is recommended to use medical grade conductive gel, similar to those used for EKG and TENS applications. A very small amount should be applied to the electrode bars prior to attaching them to the skin. Cotton swabs can be used to spread a very thin layer on the silver bars. Take care not to smudge the gel on the skin when the electrodes are placed. Any connection between the electrode bars through the conductive gel will short circuit the input of the EMG electrodes and result in erroneous readings. Ionic soap is also an excellent surfactant of this purpose. As with the gels, it should be used in extremely small quantities.
6. **Check the Reference Electrode.** It is crucial to have a well-established reference electrode contact. It may be necessary to use large EKG electrodes to ensure a high quality connection. Various samples of EKG electrodes are provided with the system. Test them to determine which is best for your application.
7. **Uncoil cables**. Any cable carrying EMG signals (electrode cables, interface I/O cables, A/D cables) should be uncoiled and allowed to drape freely.

Cables that are arranged in coils act like antennae, promoting the induction of line interference.

8. **Check the system gain.** As explained above, a small amount of line interfere will always be present on any system due to the imperfect nature of the electrode differential amplifiers. It is expected that in some cases a small amount of interference be detected when the overall channel gain is set 10000. The important point to note is that the detected EMG signal should be much larger in amplitude when compared to any recorded interference signal.

Note that it is extremely difficult to eliminate all presence of line interference. In most situations a residual amount will always be present due to the finite electrode CMRR and the imperfect electrical connections between the skin and the electrode contacts. However, with proper use of the Bagnoli-4 EMG System, this residual amount should be insignificant and in most cases not detectable when compared to the amplitude of the EMG signal.

Poor Electrode-Skin Adhesion

For best results, it is recommended to use the DelSys Interfaces to attach the DE-series EMG electrodes to the skin. Alternatively, surgical tape may be used. If the electrodes persistently fail to adhere to the skin, the following points should be addressed:

1. **Clean and dry the skin.** It is imperative that the skin be thoroughly cleaned before applying any type of adhesive. Allow the skin to completely dry after cleaning. Adhesive will not stick to wet or oily skin. Be sure to remove all hairs under the observation sites. This can be easily done with a safety razor or with commercially available hair removing lotions and waxes.
2. **Remove dry skin cells**. The human body is constantly generating skin tissue. New skin cells originate on the inner layer of the skin and grow outward towards the surface, progressing through several distinct layers and levels of activity. By the time the cells reach the skin surface, they become inactive on a cellular level and are generally considered to be dead. The body is constantly shedding this outermost cell layer, as it is replaced by the new cells from underneath. Since these inactive cells are easily dislodged from the skin, adhesives tend not to function properly when placed in contact with them. To avoid this problem, it is useful to remove the outermost layer of skin cells. This can be easily done by lining the skin with strips of surgical tape. When the tape is removed, most of these dry cells will be dislodged. This process can be repeated until satisfactory electrode adhesion is achieved.
3. **Check the shelf life of the interfaces or the tape**. The DelSys Electrode

Interfaces have a shelf life of 24 months. If the interfaces are not used within this period, the medical grade skin adhesive may begin to dry and deteriorate. The date of manufacturing can be found on the front of the package. Ensure that the time limit has not expired. Keep in mind that other adhesives such as surgical tape have similar time limitations on their shelf life.

4. **Use elastic bandages.** If difficulty in attaching the electrodes persists after addressing the above points, then one remaining alternative is to wrap the electrodes to the body with elastic bandages. Commercially available athletic wraps and bandages are suitable for this purpose if, obviously, the recording sites allow their use. Note that this method of electrode attachment is highly discouraged and should only be used as a last resort.

Excessive Presence of Motion Artifact

Motion Artifact is characterized by large amplitude, low frequency spikes which may saturate the sensitive EMG amplifiers. This type of electrical interference is usually associated with jarring motions, excessive stretching of the skin under the electrode sites and other forms of mechanical vibrations which cause movement of the electrode with respect to the skin. It is caused by a temporary fluctuation in the DC skin potential. While, the DelSys EMG systems and electrodes are specifically designed to be insensitive to fluctuations in DC skin potentials, complete immunity to motion artifact is impossible. The following points should be addressed when excessive motion artifact is present:

1. **Strong electrode-skin adhesion.** Ensure that the electrodes are robustly attached to the skin. It is crucial that there not be any electrode movement with respect to the skin at the recording site. DelSys Electrode Interfaces are specifically designed for this purpose. See the Troubleshooting section on “Poor Electrode-Skin Adhesion” if this is problem.
2. **Provide sufficient cable slack.** It is important that the electrode never be tugged by its cable. Some movements throughout an experiment may result in electrode cable tension. Take care to provide the necessary relief from cable-tension so that the electrode is not disturbed in any way.
3. **Minimize jarring motions.** Some types of activities (such as jogging) may cause vibration of the tissue located at the recording site. If possible, keep these activities to a minimum or modify them so as to reduce tissue vibration.
4. **Keep clothes clear.** If electrodes are being used underneath loose clothing, ensure that body movements do not cause the clothes to disturb the electrodes or the skin in their vicinity. Note also that many fabrics can build high electrostatic charges, which may pose operational problems for the electrodes.
5. **Ensure high quality electrical contacts**. In extreme cases it may be necessary to wet the electrode bars or use conductive gel to enhance the stability

of the electrode-skin electrical connection. See the "Troubleshooting" section on "Excessive Presence of Line Interference" for methods to ensure a high quality electrode-skin contact.

Poor or No EMG Signal at Output

In the case that an unexpected output is observed from the EMG system, the following steps may be used as guidelines in isolating and resolving the problem. It is essential to obtain an oscilloscope to carry out the steps described below. If an oscilloscope is not available, perform as many of the steps as possible with whatever data acquisition means is available.

Overall System Check

1. **Check the system power supply.** All LEDs should illuminate for approximately 1 second when the unit is initially turned on. Refer to the Troubleshooting section "System Does Not Turn 'On'" if LEDs fail to illuminate.
2. **Check all electrical connections**. Take time to ensure that the electrodes, the interfacing cables and the power cables are all correctly attached to the system. Check for obvious breaks in cables and malfunctioning connectors. All faulty cables should be replaced immediately.
3. **Check the electrode surfaces.** Make sure that the electrode bars are clean, and that both bars are in contact with the skin. Is the reference electrode correctly attached to the skin and the system?
4. **Check the system gains**. Make sure that the gain settings are appropriate for the signals you are detecting. Any channels set to REF will result in 0-volt output signal.

Individual Channel Check

1. Set all channels to the REF position. Disconnect all the BNC output connections and the 37-pin D-Sub A/D connector.
2. Connect the BNC output of Channel 1 to the input of an oscilloscope channel. The oscilloscope should be DC-coupled, with an amplitude resolution of at least 5 mV/division. The observed output should be a small-amplitude random signal, with peaks never exceeding ± 5 mV. In particularly noisy environments, a small amount of line interference may be observed. If the observed signal has amplitudes considerably larger than ± 5 mV, then extraneous noise is being produced or detected by the system. DelSys Inc. should be consulted for further assistance. *Figure 16 (a)* illustrates the typical output of a channel with gain selector set to the "REF" position.
3. Set the gain of Channel 1 to 1K. Take the reference electrode cable and press the alligator clip across both silver contacts the EMG electrode connected to Channel 1, as illustrated in *Figure 16 (b)*. Once again, the observed signal on the oscilloscope should not exceed an amplitude peak of ± 5 mV. If this is not the observed signal, contact DelSys Inc. for further as-

sistance.

4. With the gain of Channel 1 set to 1K, connect the Reference Electrode to an inactive site on the skin (such as the wrist). Place the EMG electrode over a readily available muscle site. An EMG signal should be observed for any muscular contraction located at the EMG electrode site. Consult DelSys Inc. if an EMG signal is not observed.
5. Repeat steps 2, 3 and 4 for the remaining seven channels.

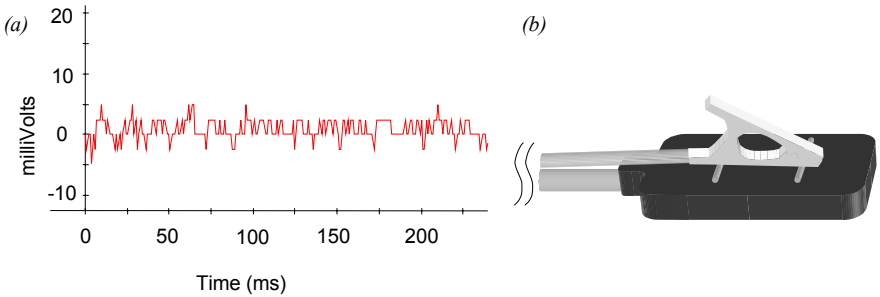


Figure 16: (a) Typical system noise. This signal is a typical sample of the Bagnoli-4 EMG system output when set on the REF position. (b) Shorting the electrode inputs. The system output should be similar to the signal displayed in (a) for a correctly functioning system.

A/D Acquisition System Check

If the A/D recording system continues to register erroneous signals even after the successful completion of the **Individual Channel Check** described above, then the problem most likely lies with the A/D acquisition system and not with the EMG system. The following steps can be used as aids in isolating the problem.

1. Inspect the A/D cable to ensure that there are no broken wires or faulty components. Connect the A/D interface cable to the A/D system and the 37-pin output connector on the Bagnoli-4 EMG System. .
2. Repeat the **Individual Channel Check** with an oscilloscope *and* the A/D system connected. If the system successfully completes the **Individual Channel Check**, and the recorded signals from the A/D system are the same as the observed signals on the oscilloscope, then the complete system should be functioning correctly. If this is not the case, choose from the following options:

3.

A. The observed signals on the oscilloscope *and* the A/D system are erroneous.
   1. Unplug the A/D cable from the Bagnoli-4 EMG system. The signals on the oscilloscope should read as expected. If they do not, repeat the **Individual Channel Check** described above. If the signals on the oscilloscope still do not read as expected, then the front stage of the A/D system is affecting the output of the EMG system.
   2. Check that the input impedance of the A/D system is at least 1 MOhm. Anything less may seriously attenuate the output signals and stress the

EMG system beyond its specifications.

3. Check that the EMG output channel signals are not connected to ground, reference, or any type of source potentials (such as a +5 V supply). Ensure that the EMG outputs are correctly wired to the A/D inputs.
4. Contact the supplier of your A/D acquisition system for further assistance.

B. The observed signals on the oscilloscope are correct, but the recorded data from the A/D acquisition system is incorrect.
   1. Check the connector configuration on the A/D cable against the pinout diagram of the 37-pin output connector of the Bagnoli-4 (refer to *Figure 10*). Make sure that the A/D inputs correspond to the correct Bagnoli-4 channel outputs. Check for breaks in the connecting cable.
   2. Make sure that the Bagnoli-4 EMG ground is connected to the analog ground of the A/D system.
   3. Ensure that the cable connecting the EMG system to the A/D system is less than 3 meters (9 ft.). Long cables increase the risk of ground loops.
   4. Run any self-calibration program that may have been included with the A/D card. Is the A/D card installed correctly? Are there any interrupt or DMA conflicts? Are the A/D range settings correct (± 5 V)?
   5. Check the sampling frequency of the A/D system. Each channel should be sampled at a minimum of 1000 Hz, since the Bagnoli-4 output bandwidth is from 20 Hz to 450 Hz. Undersampling will result in erroneous representations of the detected EMG signal.
   6. If the problem persists, contact the supplier of your A/D system.

Excessive Presence of Channel Crosstalk

Channel crosstalk is noise induced into a particular channel from the voltage signals present in adjacent channels. Some degree of channel crosstalk will always be present when dealing with multiple channel analog systems. This crosstalk can occur in the Interface I/O cable, the A/D system input cable, or even within the Bagnoli-4 EMG System itself. Precautions have been taken in the design of the unit to minimize the presence of crosstalk and its distorting effects. Despite this, some crosstalk may be present if the EMG system is outputting high voltage signals. Addressing the following points will keep crosstalk to minimum levels.

1. **Connect all A/D inputs.** A/D inputs not connected to outputs will pick up signals from adjacent A/D channels. Unused inputs should be connected to the outputs of the EMG system with the channels position set to “REF”.
2. **Set all unused channels to Reference.** Unconnected electrodes inevitably

detect line interference and surrounding electrical noise. In some cases the amplitude of the induced noise may be high enough to cause noticeable crosstalk. Setting all unused channels to the REF position eliminates crosstalk from induced noise (provided that all A/D inputs are properly connected to the Bagnoli-4 EMG system.

3. **Keep channel outputs below +/- 5 Volts**. EMG channel outputs operating at the maximum limits of this range may cause crosstalk in the A/D system cable.
4. **Do not saturate the A/D card**. Some types of A/D suffer from saturation problems if the input signals exceed the specified A/D card ranges. In these cases the saturation recovery time of the A/D card may be much longer than the channel sampling frequency. The saturated signal then appears across multiple channels, giving the impression of crosstalk. It is crucial to set the channel gains so that the voltage outputs are within the A/D card specifications.

System Does Not Turn On.

In the event that the system fails to turn on after the power switch is activated, the system power supply should be checked. Ensure that the power outlet being used is functioning safely and correctly. The output of the power supply should be 12 Volts DC. This can be checked with a voltmeter or an oscilloscope, as depicted in the *Figure 17*. If the system fails to function after it is determined that the power supply is functioning correctly, then the internal fuse will most likely need replacement. The unit should be returned to DelSys Inc., as this indicates an electrical fault and fuse can only be replaced by a qualified technician.

WARNING: Do not operate the unit with an ungrounded outlet or if the power supply is suspected to be malfunctioning.

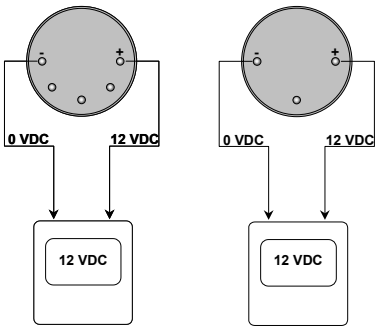
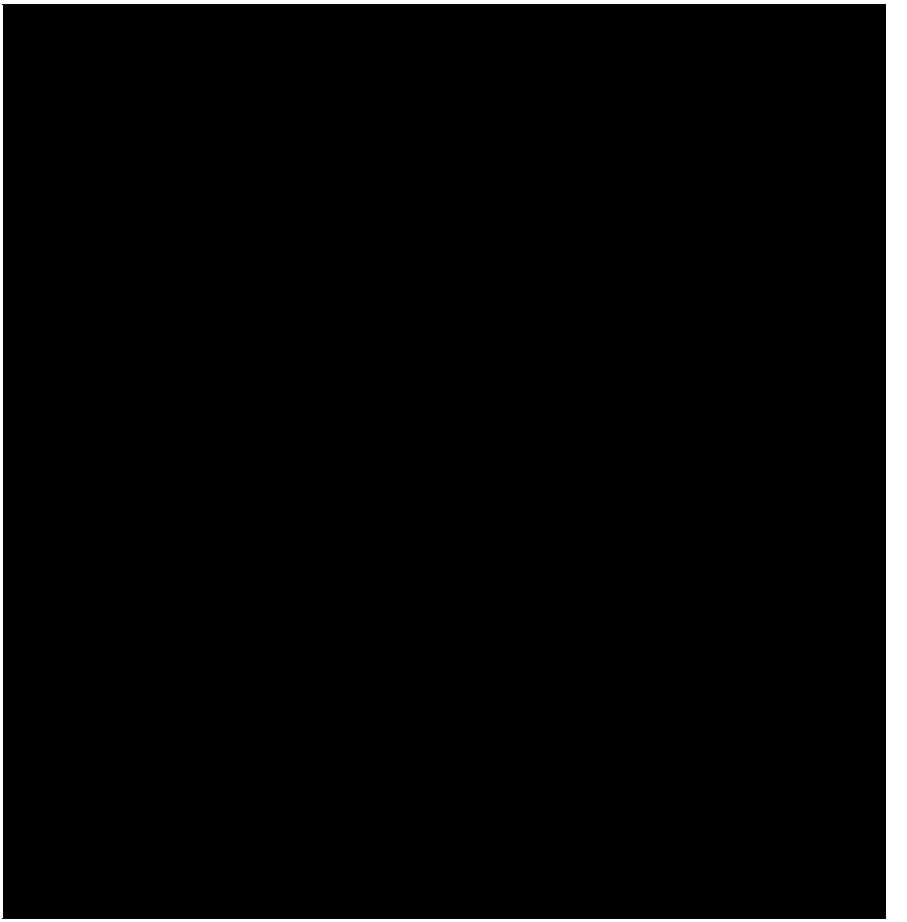


Figure 17: The output of the power supply should be 12 VDC. Voltage testing should only be carried out by a qualified technician. Take care to ensure that the voltage output pins are not shorted circuited, as this could result in permanent damage to the power supply. The domestic power supply has a 5-pin configuration, while the power supply for foreign countries has a 3-pin configuration.

Bagnoli-4 EMG System Specifications

Main Amplifier Unit



Belt-Mounted Interface Unit

DE-2.1 Electrodes

DE-3.1 Electrodes (optional)

I/O Interface Cable

Reference Electrode Cable

Glossary of Commonly Used Terms

A/D System: "Analog to Digital" System. These devices are commonly used in conjunction with computers for translating continuous (i.e. analog) voltage signals into binary (i.e. digital) data. Once in digital format, the data can be viewed, manipulated and stored on digital media devices such as disk drives and CD ROMs.

Aliaisng: A condition arising when digitally sampling a signal at a frequency less than twice the highest frequency content of the signal. Aliasing inhibits the faithful reconstruction of a digitally sampled signal. It can be avoided by ensuring that the Nyquist Criterion is not violated, which forces the representation of any frequency component in the signal with at least two samples.

BNC: "Bayonet-locking coupling" is a standard connector configuration providing quick connect and disconnect coaxial connections between instruments.. The conducting cable is completely surrounded by a flexible shield, and insulated with specially designed dielectric materials. BNC cables are commonly designed with a 50 ohm impedance.

Channel Crosstalk: In the context of this manual, this term is used to describe the electrical interference present in a particular channel as a result of the electrical signals present in other channels. This situation may arise in physically adjacent channels, and becomes more noticeable as the signal amplitude increases. This problem may be resolved by lowering the channel gains. Channels on A/D cards with unconnected (floating) inputs will typically experience channel crosstalk or "phantom" electrical signals caused by signals in other channels. This problem can be resolved by terminating all unused A/D channels to the A/D ground potential. A/D saturation may also cause channel crosstalk talk due to long recovery times of the internal A/D amplifiers. In this case, it is necessary to ensure that the amplitude of the signals input to the A/D card is never in excess of the A/D card's rated specifications.

EMG Signal Crosstalk: This term is specific to the EMG signals being recorded at the electrode site. The EMG signal detected at the skin surface is a composition of hundreds of action potentials. These action potentials can come from muscle fiber located directly below the electrode detection surface, as well as muscle fibers located adjacent to and farther away from the electrode detection surface. When the electrode detects EMG signals not only from a muscle directly beneath it, but also from surrounding muscles which may not necessary be of interest, then crosstalk from adjacent muscles is said to be present. Note that single differential electrodes have limited capacities for minimizing EMG signal crosstalk. Double differential electrodes significantly reduce this type of crosstalk as EMG signals originating from distance sources

are cancelled, while those with more immediate sources remain.

D-Subminiature (D-Sub) Connectors: Multiple-contact assemblies commonly used for connecting multi-conductor cable between equipment. These connectors are in the shape of a "D", and come with standard 0.100" inter-contact spacing as well as high-density versions with 0.050 inter-contact spacing.

Floating Signal: This term refers to the indeterminate voltage state of a terminal when it remains unconnected. If the signal terminal is not connected to any established potential (for example the Reference Potential), then it is said to be "floating". A floating signal at the input of recording devices is typically characterized by a wandering baseline voltage and may contain an inconsistent presence of line interference. Output signals of the Bagnoli-4 EMG System will float if either the EMG Electrode or the Reference Electrode is not properly connected.

Ground Potential: This the electric potential sometimes referred to as "Earth" and is connected to the metal chassis of many electrical instruments. It can act as a current sink for any line potentials which may come in contact with the chassis of instruments. Note that the Ground Potential is different than the Reference Potential. The BNC outputs and pin 19 of the D-Sub 37 connector on the rear panel of the Bagnoli-4 System are typically connected to the Ground Potential when recording instruments are used. The Reference Potential used in the differential EMG recordings is separated from the Ground Potential via channel-independent isolation transformers.

LED: "Light Emitting Diode". This is a semiconductor device which illuminates when current is allowed to flow through it. The Bagnoli-4 EMG system contains 4 LEDs which appropriately illuminate when either a "line error" or a "hi error" is detected in any one of the channels.

Line Interference: The contamination of electrical signals by the superposition of cyclic noise induced by surrounding AC power lines and sources. In North America line interference has a fundamental frequency of 60 Hz, while in most European and other foreign countries the line interference has a fundamental frequency of 50 Hz. It is extremely difficult to completely remove the presence of line interference in noisy environments. In most cases, the optimum scenario is to keep line interference to unobservably low amplitudes when compared to the EMG signal amplitude.

Motion Artifact: A transient disturbance in the detected EMG signal caused by the movement of the electrode with respect to the skin surface. Motion artifacts are undesirable and can be minimized by attaching the electrode to the skin with aggressive adhesive, by providing sufficient cable slack and by avoiding jarring motions and disturbances. Other types of transient disturbances include stimulus artifacts (caused by the applied voltage to a skin area for the purposes of eliciting

a biological response) or electrostatic artifacts (caused by static discharges detected in the vicinity of the electrode).

Reference Potential: An arbitrary voltage potential on the surface of the body used in establishing differential potential recordings. All voltages measured by the surface electrodes and propagated throughout the Bagnoli-4 EMG system have significance only when measured with respect to a well-defined Reference Potential. Note that the reference potential is **not** the same as, and is completely isolated from the Ground Potential.

Sampling Frequency: This is an important parameter characterizing A/D systems. It is defined by the number of digital samples taken of an analog signal per second. According to the Nyquist criterion, it is crucial that the sampling frequency (expressed in Hertz) be at least twice the highest frequency component of the signal being sampled, in order to correctly capture all the information in the signal, and to avoid aliasing. The Bagnoli Systems have a maximum bandwidth of 15 Hz to 500 Hz. It is thus imperative that the sampling frequency be at least 1000 Hz.

Signal Clipping: The non-linear distortion of a signal due to excessive channel amplification for the given input signal. Signal clipping on the Bagnoli Systems is indicated by the "HI" LED warning light, and can be observed when the output signals appear to be truncated at ± 5 Volts. This phenomenon is almost always caused by amplifier saturation present either in the EMG System or the A-D System. The only solution is to reduce the channel gain so that the output signals are within the ± 5 Volt specification.

Signal-to-Noise Ratio: This is a mathematical technique used to express the energy of the EMG signal compared to the energy of the noise present. The SNR is defined as V_{emg}/V_{noise} (expressed as a unitless number) or 20 $\log[V_{emg}/V_{noise}]$ (expressed in dB). Obviously, the higher the SNR, the better the quality of the recorded EMG signal.

Surfactant: This class of substances are also called surface active agents or wetting agents, and are used to reduce the surface tension of some types of cleaning solutions. Their presence in certain types of soaps can be used to facilitate ion transfer across the skin to the EMG electrode contacts.